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(57) Abstract

An austenitic stainless steel alloy is disclosed that has the following broad weight percent composition: C 0.025-0.15; Mn 4-12; Si 1.0 max.; P 0.2 max.; S 0.1 max.; Cr 15.5-17.5; Ni 1-4; Mo 0.25-1.5; Cu 1.5-4; W 1.0 max.; Co 1.0 max.; N 0.05-0.30. The balance of the alloy is iron and the usual impurities. Within the foregoing ranges, the elements are balanced such that the combined amount of carbon and nitrogen is at least about 0.19 %, the combined amount of chromium and molybdenum is less than about 17.75 % and %Cr + 3.3(%Mo) + 13(%N) > 20.5. The alloy provides a unique combination of corrosion resistance, formability, and resistance to work hardening.

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CR-MN-NI-CU AUSTENITIC STAINLESS STEEL

John H. Magee, Jr.

FIELD OF THE INVENTION

This invention relates to Cr-Mn austenitic stainless steels, and in particular to a Cr-Mn-Ni-Cu austenitic stainless steel having a unique combination of corrosion resistance in chloride-containing environments, hot workability, and resistance to work hardening.

BACKGROUND OF THE INVENTION

A known austenitic stainless steel has the following weight percent composition.

C	0.15 max.
Mn	6.4-8
Si	1.0 max.
Cr	16.5-17.5
Ni	2.5-5
Cu	2.0-3.0
N	0.2 max.
C+N	0.30 max.

The balance of the alloy is iron and the usual impurities. Data published for that alloy appears to show that the alloy has corrosive pitting resistance that is comparable to AISI Type 201L and AISI Type 430 stainless steels when determined by the anodic polarization test. The published data also shows that the pitting resistance leaves much to be desired relative to AISI Type 304 stainless steel, one of the most commonly used stainless steels. Furthermore, it has been found that commercially produced products of the aforesaid austenitic stainless steel have significantly reduced chloride crevice corrosion resistance and undergo an undesirable degree of rusting in the salt fog test.

A need has arisen for an austenitic stainless steel that has resistance to chloride pitting corrosion comparable to that of Type 304 stainless steel, but

which contains lower nickel than that alloy. It is generally known that molybdenum is beneficial to the chloride pitting corrosion resistance of an austenitic stainless steel alloy. However, molybdenum is also known to adversely affect the hot workability of such alloys and tends to upset the phase balance of such alloys because it is a strong ferrite former. In view of the foregoing, it would be desirable to have an austenitic stainless steel that provides pitting and crevice corrosion resistance comparable to Type 304 stainless steel, but which has acceptable hot workability so that it can be readily formed into a variety of product shapes.

SUMMARY OF THE INVENTION

The present invention provides an austenitic stainless steel alloy having the broad, intermediate, and preferred compositional ranges set forth below in weight percent.

Element	Broad	Intermediate	Preferred
C	0.025-0.15	0.05-0.12	0.08-0.11
Mn	4-12	6-10	7-9
Si	1.0 max.	0.75 max.	0.50 max.
P	0.2 max.	0.1 max.	0.05 max.
S	0.1 max.	0.05 max.	0.025 max.
Cr	15.5-17.5	16.0-17.0	16.25-16.75
Ni	1-4	1.5-3.5	2.0-3.0
Mo	0.25-1.5	0.5-1.2	0.7-1.0
Cu	1.5-4	2.0-3.5	2.5-3.0
W	1.0 max.	1.0 max.	0.75 max.
Co	1.0 max.	1.0 max.	0.75 max.
N	0.05-0.30	0.10-0.25	0.12-0.20
Fe	Balance	Balance	Balance

Within the weight percent limits specified above, the elements are balanced to provide the unique combination of properties that are characteristic of the alloy according to this invention. More specifically, the combined amount of chromium and molybdenum is maintained below about 17.75 wt.%; the combined amount of carbon and nitrogen is at least about 0.19 wt.%; and the alloy composition is balanced such that it contains not more than about 9% by volume (vol.%) ferrite in the as-cast condition. Further, chromium, molybdenum, and nitrogen are carefully balanced in accordance with the following relationship.

$$\%Cr + 3.3(\%Mo) + 13(\%N) > 20.5$$

This relationship defines the pitting resistance equivalent number (PRE) for this alloy. Preferably, the PRE for this alloy is greater than about 21.0.

The foregoing tabulation is provided as a convenient summary and is not intended thereby to restrict the lower and upper values of the ranges of the individual elements for use in combination with each other, or to restrict the ranges of the elements for use solely in combination with each other. Thus, one or more of the ranges can be used with one or more of the other ranges for the remaining elements. In addition, a minimum or maximum for an element of a broad, intermediate, or preferred composition can be used with the minimum or maximum for the same element in another preferred or intermediate composition. Here and throughout this application, the term "percent" or the symbol "%" means percent by weight, unless otherwise indicated.

DETAILED DESCRIPTION

In this alloy, at least about 15.5%, better yet at least about 16.0%, and preferably at least about 16.25% chromium is present to benefit the general corrosion resistance of the alloy. Chromium also contributes to the chloride corrosion resistance of this alloy. The amount of chromium in the alloy is restricted to not more than about 17.5%. better yet to not more than about 17.0% and preferably to not more than about 16.75% because too much chromium adversely affects the hot workability of the alloy.

At least about 0.25%, better yet at least about 0.5%, and preferably at least about 0.7% molybdenum is present in this alloy because it too benefits the chloride corrosion resistance of the alloy. However, too much molybdenum adversely affects the hot workability of the alloy. Therefore, the amount of molybdenum in this alloy is restricted to not more than about 1.5%, better yet to not more than about 1.2%, and preferably to not more than about 1.0%.

Chromium and molybdenum are both ferrite forming elements in this alloy. Too much ferrite adversely effects the hot-workability of this alloy. Therefore, chromium and molybdenum are restricted to avoid the formation of a deleterious amount of ferrite. As noted above, the combined amount of chromium and molybdenum (%Cr + %Mo) in this alloy is not greater than about 17.75%, and preferably, not more than about 17.5%.

Nitrogen also contributes to the chloride corrosion resistance of this alloy and benefits the austenitic phase balance of the alloy. For those reasons, the alloy contains at least about 0.05%, better yet at least about 0.10%, and preferably at least about 0.12% nitrogen. The amount of nitrogen is restricted in this alloy because too much nitrogen adversely affects the cold formability of the alloy by increasing the work hardening rate of the alloy. Therefore, the alloy contains not more than about 0.30%, better yet not more than about 0.25%, and preferably not more than about 0.20% nitrogen.

Carbon also benefits the austenitic phase balance of this alloy. Accordingly, at least about 0.025%, better yet at least about 0.05%, and preferably at least about 0.08% carbon is present in this alloy. Too much carbon leads to carbide precipitation which adversely affects the corrosion resistance and cold formability of the alloy. Therefore, the amount of carbon is restricted to not more than about 0.15%, better yet to not more than about 0.12%, and preferably to not more than about 0.11% in this alloy.

Because of the amounts of chromium and molybdenum that are present in this alloy, as described above, the alloy contains a combined amount of carbon and nitrogen (%C + %N) of at least about 0.19%, and preferably, at least about

0.25%, to avoid the formation of a deleterious amount of ferrite.

At least about 1%, better yet at least about 1.5%, and preferably at least about 2.0% nickel is present in this alloy to benefit the austenitic phase balance of the alloy. Nickel also contributes to the low work hardening rate of the alloy, and thus benefits the good cold formability of the alloy. Nickel is restricted to not more than about 4%, better yet to not more than about 3.5%, and preferably to not more than about 3.0% in this alloy.

Copper is present in this alloy because it lowers the work hardening rate of the alloy to an even greater extent than nickel. Thus, it is highly beneficial to the good cold formability of this alloy. Copper also benefits the cold formability of this alloy because it lowers the annealed strength provided by this alloy. To achieve those desired properties the alloy contains at least about 1.5%, e.g., at least about 1.6 or 1.7% copper. Better yet, the alloy contains at least about 2.0%, and preferably at least about 2.5% copper. The amount of copper is restricted because too much copper causes hot shortness, especially when the amount of ferrite in the as-cast alloy is about 9 vol.% or more. Hot shortness results in severe cracking and/or tearing of the alloy during hot working. Therefore, the alloy contains not more than about 4%, better yet not more than about 3.5%, and preferably not more than about 3.0% copper.

I have found that alloys containing as little as 9 vol. % ferrite in the as-cast condition could not be hot worked and were subject to severe cracking or tearing. To minimize hot shortness in this alloy, the composition is balanced so that the alloy contains less than about 9 vol.% ferrite in the as-cast condition. The alloy is preferably balanced such that it contains not more than about 8.5 vol.% ferrite in the as-cast condition, better yet not more than about 7 vol.% ferrite, and for best results, not more than about 6 vol.% ferrite.

At least about 4%, better yet at least about 6%, and preferably at least about 7% manganese is present in this alloy because it contributes to austenite stability, i.e., it helps to stabilize the austenite against transformation to martensite during mechanical deformation. Manganese also contributes to the

retention of nitrogen in the alloy by increasing the solubility limit of nitrogen in the solid solution. The alloy contains not more than about 12%, better yet not more than about 10%, and preferably not more than about 9% manganese because too much manganese leads to the formation of ferrite which is undesirable in this alloy.

A small quantity of silicon may be present in this alloy as a retained amount from deoxidizing additions during melting. The amount of silicon present in the alloy is restricted to not more than about 1.0%, better yet to not more than about 0.75%, and preferably to not more than about 0.50% because silicon is a ferrite forming element in this steel.

Optionally, up to about 1.0% tungsten can be present in this alloy to benefit the chloride corrosion resistance of the alloy. However, the amount of tungsten in the alloy is preferably restricted to not more than about 0.75% because tungsten is also a ferrite former in this alloy and too much tungsten adversely affects the hot workability of the alloy.

A small amount of cobalt up to about 1.0% or 0.75% may also be present in this alloy. When present, cobalt provides benefits similar to those provided by nickel and copper.

A small amount of phosphorus, up to about 0.2% or 0.1%, and/or a small amount of sulfur, up to about 0.1% or 0.05%, may be present in this alloy when desired to benefit the machinability of the alloy. However, the amounts of phosphorus and sulfur are preferably restricted because they adversely affect the corrosion resistance and formability of the alloy. Accordingly, phosphorus is preferably restricted to not more than about 0.05% and sulfur is preferably restricted to not more than about 0.025% to obtain good formability. For optimum formability, sulfur is restricted to not more than about 0.01%, and preferably to not more than about 0.005% in this alloy.

The balance of the alloy is essentially iron except for the usual impurities found in commercial grades of steels intended for similar service.

No special techniques are required in melting, casting, or working the

alloy of this invention. Arc melting followed by argon-oxygen decarburization is the preferred method of melting and refining the alloy, but other practices such as vacuum melting can be employed. In addition, this alloy can be made using powder metallurgy techniques, such as powder injection molding and metal injection molding techniques. This alloy can also be prepared using continuous casting methods.

The alloy of the present invention can be formed into a variety of shapes for a wide variety of uses. Preferred product forms include billets, bars, rod, wire, strip, plate, and sheet. The formability properties of this alloy are such that it readily lends itself to cold formed articles such as cold-drawn wire or rod. Furthermore, useful articles may be easily formed by cold bending or flattening the wire or rod that has been prepared from this alloy.

Examples

To demonstrate the unique combination of properties provided by the alloy of this invention, Examples 1 and 2 having the compositions in weight percent shown in Table 1 were prepared and tested. For comparison purposes, comparative Heats A-L with compositions outside the range of the present invention were also prepared and tested. Their weight percent compositions are also shown in Table 1.

TABLE 1

	Ex. 1	Ex. 2	Ht. A	Ht. B	Ht. C	Ht. D	Ht. E	Ht. F	Ht. G	Ht. H	Ht. I	Ht. J	Ht. K	Ht. L
C	.092	.099	.087	.091	.089	.097	.096	.050	.079	.091	.079	.095	.095	.020
Mn	7.83	7.84	7.94	7.82	7.78	7.81	7.78	7.90	6.90	7.82	6.97	8.03	8.02	1.70
Si	.66	.34	.66	.63	.62	.63	.63	.40	.35	.63	.36	.66	.66	.56
P	.073	.017	.019	.034	.034	.033	.034	.022	.028	.034	.029	.034	.034	.027
S	.002	.004	.002	.003	.002	.002	.002	.003	.005	.002	.005	.003	.003	.024
Cr	16.19	16.70	16.06	16.02	15.95	16.00	15.97	17.02	17.08	15.96	16.19	16.50	16.52	18.37
Ni	2.32	2.76	2.20	2.28	2.29	2.28	2.28	2.98	2.42	4.26	2.45	2.35	2.35	8.18
Mo	.70	.75	.27	.25	.25	.25	.25	<.01	.01	.25	.75	.26	.26	.68
Cu	2.04	2.98	2.98	2.01	2.98	2.01	3.01	2.64	2.38	3.06	2.40	.22	1.01	.39
Co	.69		.10											.36
W	.66													.09
N	.20	.16	.17	.21	.20	.12	.11	.14	.111	.11	.105	.23	.22	.081
Fe	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.
C+N	.292	.259	.257	.301	.289	.217	.206	.19	.19	.201	.184	.325	.315	.101
Cr+Mo	16.89	17.45	16.33	16.27	16.2	16.25	16.22	17.02	17.09	16.21	16.94	16.76	16.78	19.05
PRE	21.30	21.26	19.16	19.57	19.38	18.39	18.36	18.84	18.55	18.22	19.85	20.35	20.24	21.70

Heats A, F, and G are representative of the alloy described in U.S. Patent No. 5,268,510. Heats B-E and H-K are similar to Heats A, F, and G, but contain different levels of carbon, copper, nickel, molybdenum, and/or nitrogen. Heat L is representative of a commercial grade of Type 304 stainless steel.

Example 1 and Heats B to K were induction melted under a cover of argon gas and cast into 2¾ inch square ingots each weighing 17 lbs. The ingots were forged at 2200°F to 1 inch square bars. A 4″ long piece was taken from each of the bars and was milled to 7/8″ × 1″. All of the pieces were hot rolled at 2200°F to approximately 0.200″ thick strips. The strips were annealed at 1950°F for one-half hour, water-quenched, and then cleaned. Test specimens for crevice corrosion testing were prepared from the annealed material.

Heat A was prepared as a continuously-cast production size heat which was cast as 5″ square billet. An 8″ long section was cut from the billet and press forged at 2200°F to 2½″ square bar, reheated, and then forged to 1-1/16″ square bar. A 4″ long piece was cut from the 1-1/16″ bar, milled to 7/8″ × 1-1/16″, and then hot rolled to 0.250″ thick strip. The strip material was annealed at 1950°F for 1 hour, water quenched, cleaned, and then cold rolled to 0.140″ thick strip. That material was annealed at 1950°F for 15 minutes and water quenched. Test specimens for crevice corrosion testing were prepared from the annealed material.

Example 2 was induction melted under a cover of argon gas and cast as a 7½ inch square ingot. The ingot was press forged at 2200°F to 5 inch square billet. A slice was cut from one end of the billet and hot rolled to 0.200″ thick strip. The strip material was annealed at 1950°F for 45 minutes, water quenched, and then pickled. After pickling, the annealed strip material was cold rolled to 0.140″ thick and annealed again at 1950°F, this time for 15 minutes, and then water quenched. Heat L was obtained as a 4″ long by 1″ round piece taken from a production heat of Type 304 stainless steel and processed into annealed strip in a manner similar to Example 2. Specimens for crevice corrosion testing were prepared from the 0.140″ annealed strip material.

Duplicate specimens of Examples 1 and 2 and Comparative Heats A-C,

E-I, and L were tested in a solution of 5% $FeCl_3$ and 1% $NaNO_3$ for 24 hours at 10°C. If no pitting attack was observed after the first 24 hour period, then the specimen was ground and tested again at a temperature 5C° higher than the previous test temperature. Testing continued in this manner until pitting attack was observed on the specimen. The critical corrosion temperature is the highest temperature at which the specimen did not sustain any pitting.

Set forth in Table 2 below are the results of critical corrosion temperature testing of each of duplicate specimens of the examples and comparative heats in Table 1. The results are presented as the critical corrosion temperature (CCT) in °C for each specimen. Also shown in Table 2 are the Cr, Mo, and N content of each example and comparative heat and the pitting resistance equivalence number (PRE) for each example and comparative heat.

TABLE 2

Ex./Ht. No.	% Cr	%Mo	% N	PRE	CCT
1	16.19	0.70	0.20	21.30	15,15
2	16.70	0.75	0.16	21.26	15,20
A	16.06	0.27	0.17	19.16	* , *
B	16.02	0.25	0.21	19.57	* , *
C	15.95	0.25	0.20	19.38	* , *
E	15.97	0.25	0.12	18.36	* , *
F	17.02	<0.01	0.14	18.84	* , *
G	17.08	0.01	0.11	18.55	* , *
H	15.96	0.26	0.11	18.22	* , *
I	16.06	0.74	0.10	19.85	* ,10
L	18.37	0.68	0.08	21.70	20,20

* Pitting occurred at or below the initial test temperature (10°C).

The data presented in Table 2 show that Examples 1 and 2 of the alloy

according to this invention provide better resistance to chloride induced corrosion than any of the comparative heats (Heats A-C and E-I). Type 304 stainless steel (Heat L) has slightly better chloride corrosion resistance than Examples 1 and 2.

Salt spray testing was performed on a limited number of wire specimens of Example 2 and Heat A. The 0.264″ diameter specimens were obtained from production material that was hot rolled to 0.306″ round, annealed, cleaned, and then cold drawn to 0.264″ round. The wire specimens were exposed to a 5%NaCl solution at 95°F for 466 hours. At the end of the test period, the specimens of Heat A had up to 20% of the surface area rusted, whereas the specimens of Example 1 had essentially no rust. The salt spray data is additional evidence of the good chloride corrosion resistance provided by the alloy according to the present invention.

Set forth in Table 3 below are the results of a work-hardening study performed on annealed strip for several of the examples from Table 1 above including the percent cold reduction per pass (% C.R.) and the Rockwell hardness readings obtained after each reduction. In each case, the readings in parentheses are given as Rockwell B Scale (HRB) and the remaining readings are given as Rockwell C Scale (HRC). HRB is used up to a hardness value of 100, which is equivalent to HRC 22. The amount of Cu, Mo, and N in each Example/Heat is also shown for ease of comparison.

TABLE 3

% C.R.	Ex. 1 (2% Cu, .70% Mo, .2% N)	Ht. J (0.2% Cu, .25% Mo, .2% N)	Ht. K (1% Cu, .25% Mo, .2% N)	Ht. B (2% Cu, .25% Mo, .2% N)	Ht. C (3% Cu, .25% Mo, .2% N)	Ht. E (3% Cu, .25% Mo, .1% N)	Ht. L (Type 304)
0	(91.5)	(95)	(91)	(88)	(87)	(80)	---
5	(93)	(98)	(97)	(93)	(93)	(90)	(91)
10	(98.5)	28	23.5	(98.5)	(98)	(96.5)	(99)
20	28.5	34.5	31.5	29	27.5	25.5	26.5
30	34.5	39	37	35	33	31	31.5
40	37.5	43	41	37.5	35.5	34	35
50	40	45.5	42.5	40	38	37	37

The data in Table 3 show that the alloy according to the present invention has very good resistance to work hardening during cold deformation. The data also show the beneficial contribution of copper in providing a low work hardening rate in a Cr-Mn-Ni austenitic stainless steel containing molybdenum. Heats C and E have work hardening rates that are very similar to that of Type 304 (Ht. L) which contains 8% nickel. However, a comparison of the results for Heats C and E shows that even with 3% copper, increasing nitrogen has some adverse effect on the work hardening rate of a Cr-Mn-Ni austenitic stainless containing copper and nitrogen.

The terms and expressions which have been employed herein are used as terms of description, not of limitation. There is no intention in the use of such terms and expressions of excluding any equivalents of the elements or features shown and described or portions thereof. However, it is recognized that various modifications are possible within the scope of the invention claimed.

What is claimed is:

1. An austenitic stainless steel alloy having a unique combination of corrosion resistance, formability, and resistance to work hardening, said alloy consisting essentially of, in weight percent, about

	wt. %
C	0.025-0.15
Mn	4-12
Si	1.0 max.
P	0.2 max.
S	0.1 max.
Cr	15.5-17.5
Ni	1-4
Mo	0.25-1.5
Cu	1.5-4
W	1.0 max.
Co	1.0 max.
N	0.05-0.30

and the balance is essentially iron and the usual impurities; wherein

the combined amount of carbon and nitrogen is at least about 0.19%;

the combined amount of chromium and molybdenum is less than about 17.75%; and

$$\%Cr + 3.3(\%Mo) + 13(\%N) > 20.5.$$

2. An alloy as set forth in Claim 1 which contains at least about 6% manganese.

3. An alloy as set forth in Claim 1 which contains at least about 1.5% nickel.

4. An alloy as set forth in Claim 1 which contains at least about 0.5% molybdenum.

5. An alloy as set forth in Claim 1 which contains at least about 16.0% chromium.

6. An alloy as set forth in Claim 1 which contains less than 9 vol. % ferrite in the as-cast condition.

7. An alloy as set forth in Claim 1 which contains not more than about 8.5 vol. % ferrite in the as-cast condition.

8. An alloy as set forth in Claim 1 wherein %Cr + 3.3(%Mo) + 13(%N) > 21.0.

9. An alloy as set forth in Claim 1 wherein the combined amount of chromium and molybdenum is not more than about 17.5%.

10. An austenitic stainless steel alloy having a unique combination of corrosion resistance, formability, and resistance to work hardening, said alloy consisting essentially of, in weight percent, about

	wt. %
C	0.05-0.12
Mn	6-10
Si	0.75 max.
P	0.1 max.
S	0.05 max.

Cr	16.0-17.0
Ni	1.5-3.5
Mo	0.5-1.2
Cu	2.0-3.5
W	1.0 max.
Co	1.0 max.
N	0.10-0.25

and the balance is essentially iron and the usual impurities; wherein

the combined amount of carbon and nitrogen is at least about 0.19%;

the combined amount of chromium and molybdenum is less than about 17.75%; and

$$\%Cr + 3.3(\%Mo) + 13(\%N) > 20.5.$$

11. An alloy as set forth in Claim 10 which contains at least about 7% manganese.

12. An alloy as set forth in Claim 10 which contains at least about 2.0% nickel.

13. An alloy as set forth in Claim 10 which contains at least about 0.7% molybdenum.

14. An alloy as set forth in Claim 10 which contains at least about 16.25% chromium.

15. An alloy as set forth in Claim 10 which contains less than 9 vol. % ferrite in the as-cast condition.

16. An alloy as set forth in Claim 10 which contains not more than about 8.5

vol. % ferrite in the as-cast condition.

17. An alloy as set forth in Claim 1 wherein %Cr + 3.3(%Mo) + 13(%N) > 21.0.

18. An alloy as set forth in Claim 10 wherein the combined amount of chromium and molybdenum is not more than about 17.5%.

19. An austenitic stainless steel alloy having a unique combination of corrosion resistance, formability, and resistance to work hardening, said alloy consisting essentially of, in weight percent, about

	wt. %
C	0.08-0.11
Mn	7-9
Si	0.50 max.
P	0.05 max.
S	0.025 max.
Cr	16.25-16.75
Ni	2.0-3.0
Mo	0.7-1.0
Cu	2.5-3.0
W	0.75 max.
Co	0.75 max.
N	0.12-0.20

and the balance is essentially iron and the usual impurities; wherein

the combined amount of chromium and molybdenum is not more than about 17.5%; and

%Cr + 3.3(%Mo) + 13(%N) > 21.0.

20. An alloy as set forth in Claim 19 wherein the combined amount of carbon and nitrogen is at least about 0.25%.

INTERNATIONAL SEARCH REPORT

Inter. nal Application No
PCT/US 99/25478

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 C22C38/42 C22C38/44 C22C38/58

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 C22C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 694 626 A (ACERINOX SA) 31 January 1996 (1996-01-31) claim 1; examples	1-20
A	PATENT ABSTRACTS OF JAPAN vol. 1995, no. 02, 31 March 1995 (1995-03-31) & JP 06 306544 A (NIPPON STEEL CORP), 1 November 1994 (1994-11-01) abstract	
A	GB 2 075 550 A (ARMCO INC) 18 November 1981 (1981-11-18)	
A	US 3 756 807 A (HOSHINO K ET AL) 4 September 1973 (1973-09-04)	

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 March 2000	30/03/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Ashley, G

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INTERNATIONAL SEARCH REPORT

..formation on patent family members

Inter. nal Application No
PCT/US 99/25478

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
EP 0694626	A	31-01-1996	NONE			
JP 06306544	A	01-11-1994	NONE			
GB 2075550	A	18-11-1981	DE	3117539	A	04-03-1982
			FR	2485040	A	24-12-1981
			JP	57035668	A	26-02-1982
			SE	453998	B	21-03-1988
			SE	8102721	A	06-11-1981
US 3756807	A	04-09-1973	BE	754371	A	18-01-1971
			CA	934192	A	25-09-1973
			CH	512589	A	15-09-1971
			DE	2047660	A	16-03-1972
			ES	381536	A	01-04-1973
			FR	2074865	A	08-10-1971
			GB	1331770	A	26-09-1973
			ZA	7005987	A	28-04-1971